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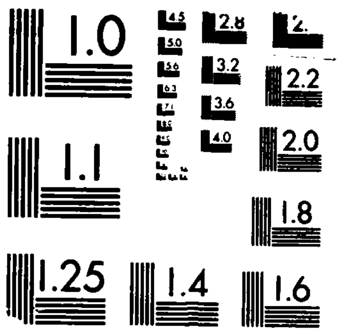
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Variability in Intake and Dehydration in Young Men During a Simulated Desert Walk

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ABSTRACT

Voluntary dehydration was examined in young unacclimatized men walking under simulated desert conditions. Thirty-three subjects (20-33 yrs) walked on a treadmill (4.82 $km \cdot h^{-1}$, 5% grade) for 30 $min \cdot h^{-1}$ for 6 h in a hot environment (40°C db/ 26°C wb, 4.02 $km \cdot h^{-1}$ windspeed). Cool (15°C) water was provided <u>ad libitum</u> in canteens. Two subpopulations of individuals were identified: those drinkers (D) (n=20) who maintained body weight loss at less than 2% (0.44-1.88%) and those who were reluctant to drink (reluctant drinkers, RD) (n=13) and lost more than 2% body weight (BW) ~~(2.07-3.51%)~~ despite the continual availability of cool water. RD consumed 31% less water ~~(2.05 ± 0.14 kg)~~ than D ~~(2.98 ± 0.12 kg)~~, and this resulted in a significantly greater BW loss in RD ~~(2.65 ± 0.11%)~~ than D ~~(1.16 ± 0.11%)~~. However, the only statistically significant differences in plasma indices of hypohydration were the higher final plasma Na+ and protein levels in RD. Rectal temperature was higher in the RD, whereas final heart rates were unaffected. Our results indicate that about 40% of young adult males may be reluctant to drink, and thus will voluntarily dehydrate even when given cool water <u>ad libitum</u> during intermittent exercise in the heat. The reduced intake of reluctant drinkers may be critical in predisposing them to increased risk of dehydration and heat injury.

Index Terms: heat, exercise, rehydration, drinking, water balance

INTRODUCTION

Men living and working for prolonged periods in hot environments nearly always become dehydrated since they rarely voluntarily drink sufficient fluids to replace quantities lost in sweat. Adolph (1) noted that dehydration of 2 to 3% of body weight may be commonplace when working in the desert even if water is plentiful and palatable. Varying degrees of dehydration ranging from 1.5% to 7% loss of body weight have been reported under both field and laboratory settings in men working in hot climates (1, 3, 11, 14, 16, 20, 22), as well as in marathoners running in temperate climates (17). Rothstein et al. (20) concluded that the phenomenon of voluntary dehydration results from an inadequacy of the thirst mechanism to stimulate sufficient drinking for complete rehydration.

Holmes and Gregerson (13) reported a marked variability in the drinking response both as to timing and quantity drunk among dogs. The authors concluded that the large sample (40 dogs) enabled them to observe a range of drinking patterns in response to an injection of hypertonic NaCl. This wide range of drinking behavior suggests significant inter-individual variability in the pattern of drinking responses to a single stimulus among a group of physiologically homogeneous subjects.

These latter findings prompted us to assess the fluid consumption and subsequent dehydration in young adults during a prolonged treadmill walk under simulated desert conditions when cool water was available *ad libitum*. Unlike the previous studies (1, 12, 16, 20, 22), we measured the extent of voluntary dehydration in a large population (n=33) of

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young adult males exercising at a constant work level under controlled environmental conditions. In contrast to prior studies on dehydration, cool water at a temperature preferred for drinking (7, 21) was given to minimize the effects of negative alliesthesia (8, 14, 21). Because water temperatures ranging from 10° to 15°C have been shown to be preferred by humans when large quantities must be drunk to reduce hypohydration (1, 7, 21, 22), water at 15°C was chosen. Additionally, the impact of the various levels of dehydration on several physiological responses was assessed.

METHODS

Subjects: Thirty-three (33) healthy unacclimatized male volunteers were recruited based on age, inexperience with water balance studies, and subject availablility. Physical characteristics (mean $\pm$ SEM) of the group were: 179.6 $\pm$ 1.5 cm height, 77.13 $\pm$ 1.82 kg weight, and 23.6 $\pm$ 0.5 yr (range= 20-33 yr). Prior to testing, each subject was informed of the test design and procedures, medical risks, and his right to terminate participation at any time without retribution. During the oral briefing of test subjects, we did not emphasize the importance of the *ad libitum* fluid intake and body weight measurements.

Experimental Design: The study was conducted in a climatic chamber between mid-November and February; thus none of the subjects were naturally acclimatized to the heat. Chamber conditions were maintained at 40°C dry bulb, 30-40% R.H. and a 4.02 $km \cdot h^{-1}$ windspeed providing a WBGT of about 30°C.

Subjects wore shorts, socks, underpants, and sneakers, and walked on a treadmill (4.82 $km \cdot h^{-1}$, 5% grade) for 30 min of each hour. During the remaining 30 min of each hour, subjects were sedentary; thus, at the end of each 6 h trial, each subject had walked 14.5 km and climbed 724 m.

Cool (15^{o}C) tap water (municipal water supply, Natick, MA) treated with military-issue iodine (I_2) disinfectant tablets (16 $mg \cdot L^{-1}$) was provided ad libitum during the 6 hours in the chamber. Water was provided in coded canteens placed within comfortable reach of each subject. Voluntary dehydration and fluid balance were assessed through analyses of water intake, body weight loss, plasma electrolyte changes, and heat strain indices.

Measurements: Following breakfast at 0700 hours, subjects voided a pretest urine sample for determining initial hydrational status by specific gravity. Additional urine samples were collected, weighed and analyzed. Initial nude body weight (Sauter balance, ± 10g), clothed-instrumented weight, age and height were recorded. Clothed-instrumented body weights were taken prior to the start of the first 30 min of exercise, and were repeated at the end of each subsequent 30 min walk and recovery period. Fluid intake was measured by weighing (Sartorius, ± 1g) the canteens at each 30 min interval, or when canteens were refilled. Lunch was provided during the third recovery period (2.5-3.0 hours).

After entering the climatic chamber, subjects remained standing for 20 min after which a baseline (PRE-EX) venous blood sample was drawn from a superficial arm vein. After the sixth walk (5 hours), a final

blood sample (POST-EX) was obtained. Hematocrit (Hct) was measured using the microhematocrit technique and hemoglobin was determined by the cyanmethemoglobin method. The change in plasma volume (POST-EX versus PRE-EX) was calculated (10). Serum was analyzed for electrolytes (flame photometry), osmolality (freezing point depression) and total protein (refractometer).

Subjects were fitted with standard ECG electrodes, a rectal probe (inserted to a depth of 10 cm), and three skin thermocouples (chest, calf and arm) from which heart rate, rectal temperature and mean weighted skin temperature were continuously monitored.

Group comparison t-tests and ANOVA's were performed to evaluate the effects of drinking on the physiological responses to exercise in the heat. The null hypothesis was rejected at $p<0.05$. Some of the body weight loss and fluid intake data were presented at a symposium (24).

RESULTS

During the entire 6 h test interval, the 33 subjects consumed (mean $\pm$ SEM) 2.61 $\pm$ 0.12L of cool water yet still lost 1.75 $\pm$ 0.15% of their

Fig. 1 initial body weight. As shown in Fig. 1, marked inter-individual variability was noted in both the amount of body weight lost and the amount of cool water consumed during the 6 h. Individual 6 h body weight deficits (Fig. 1, lower panel) ranged from 0.44% to 3.51% of initial body weight while *ad libitum* fluid intake (Fig. 1, upper panel) ranged from 1.04L to 3.81L.

Since a 2% loss of initial body weight has generally been accepted as a threshold for thirst stimulation (1, 11, 20, 22), we chose this criterion for identifying the 20 individuals who maintained body weight

losses less than 2% (DRINKERS, D) and those 13 subjects who were reluctant to drink and lost more than 2% of their initial body weight (RELUCTANT DRINKERS, RD). No differencs in physical characteristics

Table 1 (Table 1) or PRE-EX heat strain indices (Table 2) or serum chemistries

Table 2
Table 3 (Table 3) were found between D and RD.

Mean 6 h body weight losses for the D and RD were 1.16 $\pm$ 0.11% and 2.65 $\pm$ 0.11%, respectively. The greater weight deficit in RD was

Fig. 2 apparent even within the first 30 min ($p<0.05$) (Fig. 2, upper panel). The increased dehydration observed in the 13 RD was due to insufficient water intake since significant differences in consumption ($p<0.05$) were observed during the first 30 min walk (Fig. 2, lower panel), as well as the entire 6 h experimental interval (2.05 $\pm$ 0.14L RD vs 2.98 $\pm$ 0.21L D, $p<0.001$).

Exercise in the heat elicited significant elevations ($p<0.05$) in rectal temperature (Tre), heart rate (HR) and plasma protein, and reductions in mean weighted skin temperature (Tsk) and plasma volume (% PV) in both groups (Table 2). RD also manifested higher Tre ($p<0.05$) and plasma protein ($p<0.01$) at the end of 6 h. Hct, % PV, and HR were not significantly different between groups. The single difference in plasma sodium (PNa+) and plasma potassium (PK+) (Table 3) between the two groups occurred after 6 h (PNa+ elevated, RD).

DISCUSSION

Our study assessed the variability of fluid consumption and voluntary dehydration and their impact on several physiological variables in a large subject population of unacclimatized young adult

men during recurrent exercise in a desert-like environment. Two unique findings emerged from this study: 1) a striking variability in both fluid intake and therefore body weight loss in young men when exercising at similar work levels and 2) 39% of these subjects were reluctant to drink and lost 2.65% of their initial body weight during the 6 h despite the continuous availability of cool (15°C) water. The differences in percent body weight lost (Fig. 2, upper panel) and fluid intake (Fig. 2, lower panel) between D and RD were apparent as early as the first 30 min walk and increased with time. Individual differences in fluid consumption (3.7-fold) and percent body weight loss (8-fold) were observed by the end of 6 h. These ranges of body weight loss and fluid consumption provide a better characterization of the extent of voluntary dehydration which can occur during exercise in the heat.

Rothstein et al. (20) noted body weight losses varying from 1.5 to 5.2% in men marching or operating equipment for as few as 3.5 h under warm field conditions. Inadequate fluid intake during 3.5 to 6 h of intermittent treadmill exercise resulted in reports of weight losses ranging from 0.5 to 3.5% (1, 3, 9, 12, 14, 16, 20, 22), and deficits up to 10% have been documented in marathoners (17). Bar-Or et al. reported that unless forced to drink, 10 to 12 year old boys (4) and adults (5) progressively dehydrated at a uniform rate during intermittent cycling in a hot climate. Although variable levels of hypohydration were noted in the above studies, environmental conditions, work intensities, palatability of beverages, and physical characteristics of test subjects also varied.

While previous studies have not examined the extent of variation in voluntary dehydration within a given subject population or under constant conditions, intersubject variability in the drinking response to a constant stimulus with respect to both timing and amount consumed has been reported in both humans (15) and dogs (13). Additionally, Holmes and Gregerson (13) concluded that their large sample size enabled them to observe not only significant differences in drinking patterns, but also remarkable intra-individual consistency. Phillips et al. (15) observed reduced water intake following 24 h fluid deprivation in elderly compared to young men and attributed this to a deficit in thirst. Consumption varied by 430-500 $ml \cdot kg^{-1}$ body weight for a 60 min rehydration period, with the elderly drinking about 50% of that drunk by the younger men.

We observed that D rehydrated to 76 $\pm$ 2% of initial body weight (range= 49-93%) whereas the RD rehydrated only 50 $\pm$ 2% (range= 31-59%) during the 6 h of intermittent walking. The lower fluid intake in RD contributed to the significant differences in weight loss since 6 h sweat losses (4.08 $\pm$ 0.10L) were nearly identical for the two groups. Earlier experiments in our laboratory yielded average rehydrations of 60% (14) and 80% (3) for sweat losses of 3.92L and 3.4L, respectively. In the study of Phillips et al. (15), elderly and young men rehydrated by only 16% and 30%, respectively, after a 24 h period of fluid deprivation. Although adequate hydration is instrumental in maintaining heat balance (1, 9, 11,16, 23), men working in the heat rarely replace more than two-thirds of the water lost in sweat. Man requires at least 30 minutes to accomplish 80% of total rehydration (1, 20), and during

the first 15-20 minutes, drinking is copious (20). Rolls and coworkers (19) reported that following 24 h of fluid deprivation, 65% of the total intake during the first hour was consumed in the initial 2.5 minutes. In comparison, Sohar et al. (22) recommended at least 20 min for adequate rehydration between work bouts. Regardless, the mechanisms regulating the duration and amount of fluids drunk in response to dehydration are not known, and probably differ quantitatively between species (1, 18, 19).

Adolph and coworkers (1) reported that soldiers who maintained hydration via forced drinking performed better than those who drank ad libitum. Many studies have shown the detrimental effects of dehydration; 2 to 5% loss of body weight can cause lassitude, apathy, anorexia, and reduced work performance (1, 16, 22, 23) concomitant with elevations in core temperature, heart rate, and risk of heat injury (1, 3, 4, 5, 9, 11, 16, 22, 23). In both of our groups, we observed increases in heart rate and rectal temperature which, as previously noted (4, 5, 9, 11, 23), were in proportion to the level of dehydration. Our data show that for each percent of body weight lost, heart rate rose 6 bpm and rectal temperature increased 0.05°C. Bar-Or et al. (4) reported a 0.28°C rise in rectal temperature with each 1% loss in body weight in young boys cycling on an ergometer. Not surprisingly, the best of our D had significantly less body weight loss (0.44%) and lower maximal Tre (37.93°C) and HR (116 bpm) than the worst of our RD who lost 3.51% of his body weight and manifested a maximal Tre Of 38.51°C and HR of 150 bpm.

All of our subjects began the study in a euhydrated state; breakfast beverages were provided, specific gravities on post-breakfast urine samples indicated adequate hydrational status ($U_{SG} = 1.024 \pm 0.001$) and each subject consumed an additional 250 ml of water about 30 min before the first walk. No differences in physical characteristics, pre-exercise thermoregulatory indices and plasma chemistries were noted between the two groups, as shown in Tables 1, 2, and 3. Sweat loss was not significantly affected by the levels of dehydration observed in this study (3, 9, 11, 14). The 6 h sweat losses were not different between the two groups and were independent of dehydration level in the range of 0-3.5% body weight loss. Also, no differences in mean weighted skin temperatures were seen between the two groups (3). We conclude that there are no differences in the physiological or physical traits examined in this study to distinguish the RD from an individual that drinks.

Two difficulties in ascribing factors responsible for initiating, maintaining and terminating drinking in humans are: 1) drinking activity ceases well before osmolar or volume changes in either the cellular or extracellular environment can be measured (1, 2, 6, 18) and 2) some degree of satiation of thirst occurs during the course of drinking (18, 19). Using a design wherein the first h of rehydration after 24 h of fluid deprivation, Roll and coworkers (18, 19) noted that subjective sensations of thirst and systemic factors (cellular and extracellular dehydration) contribute to the initiation of drinking. While preabsorptive factors (oropharyngeal stimulation, gastric distention and palatability of beverages) contribute to the early decline in drinking,

post-absorptive factors maintain satiety. The contribution of each of these mechanisms to the regulation of ad libitum drinking during exercise/heat stress regimens is unknown.

An unresolved issue is the incomplete rehydration most notably seen in the individuals reluctant to drink despite marked fluid deficits. Several reasons for the different drinking behaviors in our D and RD may include perception of mouth dryness and taste (14, 18, 19, 21), perception of thirst (1, 15, 18, 19, 21, 22), degree of gastric distention (18, 19), hot weather experience, background, and tolerance to fluid deprivation (1). Subjective ratings of thirst and mouth dryness are correlated with drinking (15, 19). While Rolls et al. (18, 19) concluded that gastric distention is important in the early phase of satiation and cessation of drinking, others (21) reported that stomach fullness does not account for incomplete rehydration post-exercise. In the present study, the backgrounds and hot weather experience of the two groups were similar.

Of importance is the finding that preferences, hedonic ratings and consumption are not always related (7, 21). Cabanac (8) proposed using the word "alliesthesia" to describe the phenomenon in which a stimulus can produce either pleasant or unpleasant sensations depending on an individual's internal state. Boulze et al. (7) reported that intake decreases with colder water because of its high satiating effects but decreases with warming temperature because of its non-palatability. A positive alliesthesia for cold water during exercise in a hot environment due to hyperthermia, but not dehydration, was reported by Hubbard and coworkers (14). Moreover, these investigators demonstrated

that palatability factors can enhance positive alliesthesia (14). Alliesthesia for water at a given temperature during the course of rehydration was also shown by Rolls et al (19). Because we did not measure the subjects' thirst ratings, mouth dryness, discomfort, or hedonics, the contribution of a lack of thirst or other oropharyngeal stimulus to the current results is unknown. Potential differences between D and RD may be perception of temperature, taste, and change in hedonics during the course of rehydration or exercise.

In summary, this study demonstrated a marked variability in dehydration in adult men exercising intermittently in a hot climate. Only 20 of the 33 men consumed sufficient fluids to maintain their hydration at less than a 2% body weight loss during the 6 h. Test subjects who drank less water had greater fluid deficits and consequently higher exercising rectal temperatures and heart rates.

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Table 1. SUBJECT PHYSICAL CHARACTERISTICS

	AGE (yr)	WEIGHT (kg)	HEIGHT (cm)	U_{SG}
DRINKERS	23	78.6	181	1.024
	±1	±2.4	±2	±0.001
RELUCTANT DRINKERS				
	24	74.9	177	1.023
	±1	±2.8	±2	±0.001

Values are mean ± SEM for 20 Drinkers and 13 Reluctant Drinkers.

Table 2. EFFECT OF FLUID INTAKE ON HEAT STRAIN INDICES

	Tre (°C)	Tsk (°C)	HR (bpm)	Hct (%RBC)	Total Protein ($g \cdot 100\ ml^{-1}$)	PV (%)
DRINKERS						
PRE-EX	36.99	35.3	84	43.2	7.3	---
	±0.04	±0.1	±3	±0.6	±0.1	
POST-EX	37.97*	34.9	131*	43.2	7.6*	-0.3
(walk 6)	±0.07	±0.3	±3	±0.5	±0.1	±1.1
RELUCTANT DRINKERS						
PRE-EX	37.01	35.2	82	42.4	7.4	---
	±0.04	±0.1	±3	±0.8	±0.1	
POST-EX	38.18*#	34.6*	135*	42.7	8.3*#	-3.4
(walk 6)	±0.06	±0.2	±3	±0.8	±0.2	±1.6

Values are means ± SEM. N= 20 Drinkers and N= 13 Reluctant Drinkers. Rectal temperature (Tre), mean weighted skin temperaure (Tsk) and heart rate (HR) were measured at the end of Walk 6; hematocrit (Hct), total protein, and the change in plasma volume (% PV) were measured 20 min post-walk 6 (POST-EX).

* $p<0.05$ for pre-exercise vs walk 6 or post-walk 6.

# $p<0.05$ for Drinkers vs Reluctant Drinkers.

Table 3. EFFECT OF FLUID INTAKE ON SERUM CHEMISTRIES

	Posm ($mOsm \cdot kg\ H_2O^{-1}$)	P_{Na^+} ($mEq \cdot L^{-1}$)	P_{K^+} ($mEq \cdot L^{-1}$)
<u>DRINKERS</u>			
PRE-EX	289	141	4.4
	±1	±1	±0.1
POST-EX	289	140*	4.6*
(walk 6)	±1	±1	±0.1
<u>RELUCTANT DRINKERS</u>			
PRE-EX	288	144	4.3
	±1	±2	±0.1
POST-EX	291	145#	4.5*
(walk 6)	±1	±2	±0.1

Values are mean ± SEM. n=20 Drinkers, n=13 Reluctant Drinkers. Plasma osmolality (Posm), sodium (P_{Na^+}), and potassium (P_{K^+}) were measured 20 min post-walk 6 (POST-EX).

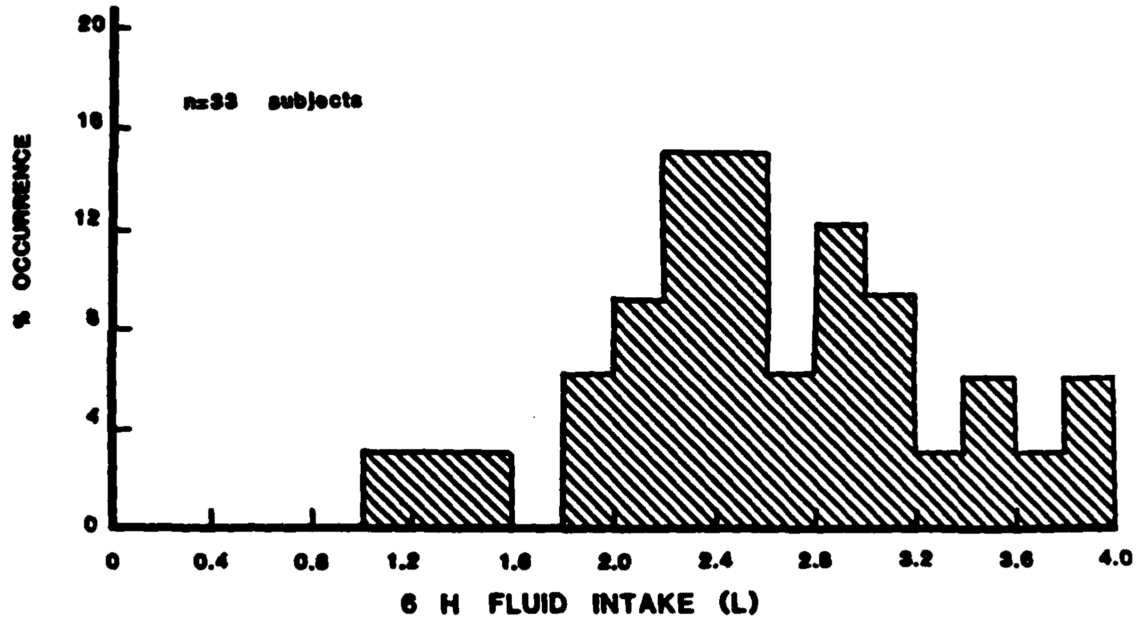
* $p<0.05$ for PRE-EX vs POST-EX.

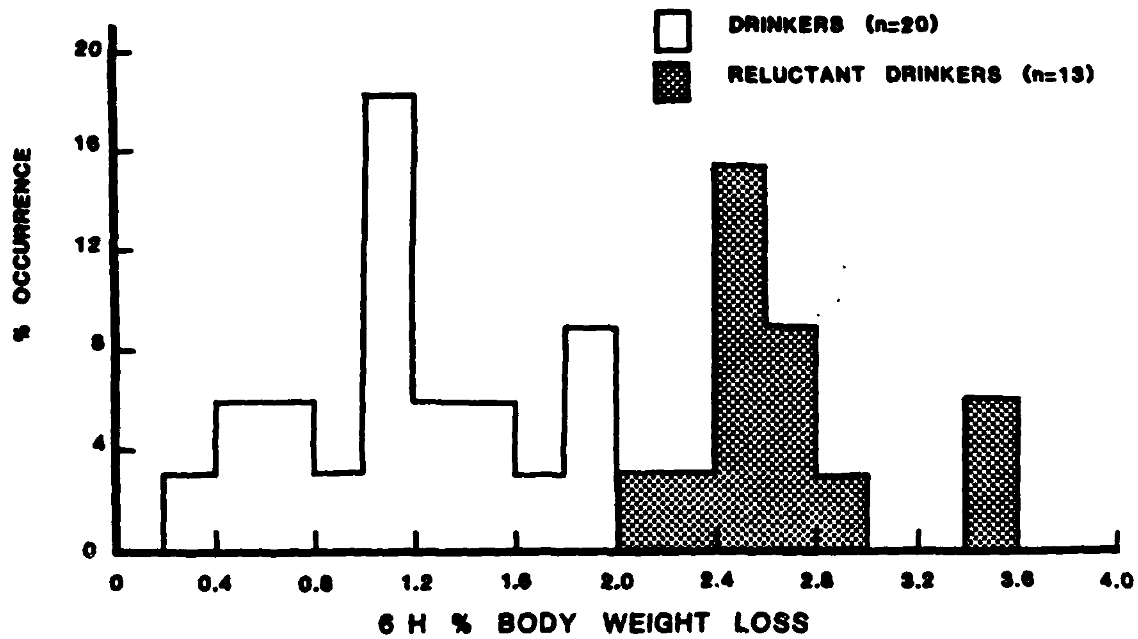
# $p<0.05$ for Drinkers vs Reluctant Drinkers.

FIGURE LEGENDS

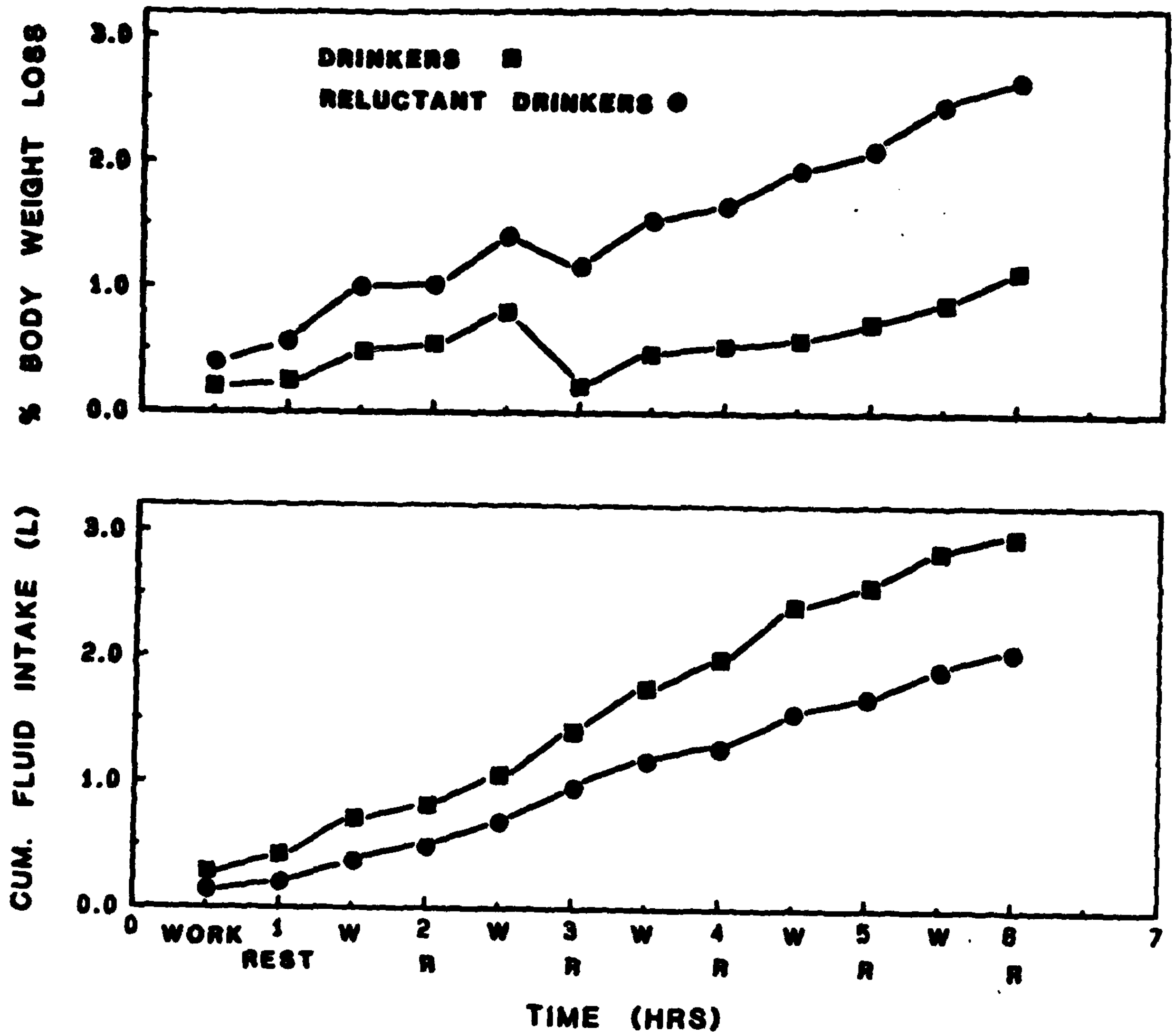
Fig. 1. Frequency distribution of six (6) hour fluid intake in liters (upper panel) and of six (6) hour percent body weight loss (lower panel) in 33 subjects drinking cool (15^{o}C) water.

Fig. 2. Cumulative percent body weight loss (upper panel) and cumulative fluid intake in liters (lower panel) of drinkers and reluctant drinkers consuming cool (15^{o}C) water.


n=33 subjects
% OCCURRENCE
20
16
12
8
4
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
6 H FLUID INTAKE (L)


DRINKERS (n=20)
RELUCTANT DRINKERS (n=13)
% OCCURRENCE
20
16
12
8
4
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
6 H % BODY WEIGHT LOSS

COOL (15°C) IODINATED (I_2) WATER



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